

necessary to determine in advance what type of pressure distribution will prevail throughout the season.

Differences in pressure on the earth's surface, Prof. Henry said:

are largely dynamic results due to motions of the atmosphere, and likewise the areas of high barometer and low barometer, respectively, may also be largely due to the aforesaid motions, but the ultimate cause of their formation is due to differences in the density of the atmosphere, which in turn are due to differences in temperature and moisture distribution.

Because of the importance of these motions causing changes in the character of the high and low barometric areas over the north Pacific Ocean, Prof. Henry thinks there is need above all else of more well established facts concerning the weather conditions which result from them. These facts are not at hand, and hope of obtaining them rests largely in the rapid multiplication of ship observations throughout the vast expanse of the Pacific Ocean.

SEASONAL FORECASTING OF PRECIPITATION—PACIFIC COAST.¹

551.509 : 551.578.1 (79) BY ALFRED J. HENRY, METEOROLOGIST.

[Weather Bureau, Washington, Mar. 8, 1921.]

SYNOPSIS.

An examination is made of the observational data of past years bearing upon the subject. This examination shows clearly that the distribution of precipitation in Pacific Coast States is not, as a rule, of the same order of intensity, indeed fairly heavy precipitation in Washington and Oregon may be associated with deficient rainfall in California, and vice versa. The physical grounds for the difference in distribution are next sought. Three classes of seasonal distribution are distinguished, and these in turn are discussed with reference to their probable causes.

The conclusion is reached that a knowledge of the pressure distribution over the northeastern portion of the Pacific Ocean and the Canadian Northwest affords the most hopeful avenue of approach to a rational solution of the problem.

The annual precipitation in Pacific Coast States ranges from a few inches in extreme southeastern California to more than 100 inches in the foothills of western Oregon. There is thus a very pronounced increase in precipitation with increase in latitude, which is more noticeable in California than in either Washington or Oregon. The greatest contrasts, however, are those between the precipitation of the lowlands and that of the mountain masses which parallel the great interior valleys. This contrast is greater on the leeward than the windward side of the higher mountains.

Perhaps nowhere in the North American continent is the seasonal character of the annual precipitation so conspicuous as in California, where more than 50 per cent of the annual precipitation occurs in the three winter months of December to February, while the months of June to September are practically rainless, except upon the higher mountain summits.

Statistics available.—The most readily available statistics for the region under consideration are those found in Table 1 of the MONTHLY WEATHER REVIEW. This table, in very nearly its present form, was begun in the last half of 1884; at that time it bore the heading "Table of Miscellaneous Meteorological Data, Signal Service Observations" in the beginning the monthly departures were not known. It is fairly complete in the last respect after 1892, although strictly speaking the homogeneity of the record is not as great as could be desired. The exigencies of the service at times made it necessary to discontinue an observing station or to remove it a short distance from its original location. Most of the changes in the observing stations that took place during the 29 years considered were of that order. The original sta-

Should these be forthcoming, he says:

It may be possible to discover the preliminary symptoms of the changes in position and intensity of the Pacific high, which, if accomplished, will be a forward step toward the goal.

Prof. Henry does not believe that an examination of rainfall records of the past would be worth while, as a comprehensive analysis has already been made of many of them without discovering any periodicities that could be used for forecasting purposes.

He does not think the matter is definitely settled in the negative, but believes we must wait upon civilization and settlement in unrepresented districts for further observations, and when they are obtained additional light will be thrown upon that which is now obscure. Our best efforts in the meanwhile "should be directed toward the enlistment of more and more ship captains in the meteorological service."

tions in the north Pacific coast region were: Fort Canby, Neah Bay, Olympia, Port Angeles, Tatoosh Island, Wash., and Astoria, Oreg. For the middle Pacific coast region in 1892, the following named stations were used: Eureka, Point Reyes, and San Francisco, all on the coast, and Red Bluff and Sacramento in the interior. The south Pacific coast region was represented by the stations at San Diego, and Los Angeles one of which is on the coast, the other but a short distance therefrom. The interior of southern California was represented by the station at Fresno. The original table above referred to gives the mean precipitation for the month for each of the three districts and the departure from the normal the latter being computed from those records of 10 to 20 years in length. I have combined the departures from the normal of the three winter months, into a single expression which represents the abnormality of the winter as a whole beginning with December, 1891, and continuing through until February, 1920; thus in Table 1, which immediately follows, the figures 2.5 inches, 2.9 inches, 2.9 inches in the columns headed "North," "Middle," and "South," respectively, indicate that precipitation for the winter 1891-92 was deficient by these amounts in the respective districts. The full-faced figures indicate positive departures, while negative departures are printed in the ordinary type. These figures are obtained by adding algebraically the departures of the three winter months; they represent, therefore, the total or accumulated departure and not the mean departure.

TABLE 1.—Winter precipitation departures—Pacific Coast States.

[Accumulated departures in inches and tenths.]

| Years. | North coast. | Middle coast. | South coast. | Years. | North coast. | Middle coast. | South coast. |
|----------------|--------------|---------------|--------------|--------------|--------------|---------------|--------------|
| 1891-92..... | 2.5 | 2.9 | 2.9 | 1906-7..... | 3.8 | 2.7 | 2.9 |
| 1892-93..... | 3.0 | 1.7 | 1.5 | 1907-8..... | 0.5 | 1.3 | 0.9 |
| 1893-94..... | 3.0 | 1.8 | 2.7 | 1908-9..... | 1.6 | 8.6 | 5.6 |
| 1894-95..... | 7.1 | 5.4 | 3.2 | 1909-10..... | 3.2 | 3.2 | 2.0 |
| 1895-96..... | 9.5 | 3.3 | 4.2 | 1910-11..... | 5.2 | 2.3 | 3.6 |
| 1896-97..... | 2.4 | 0.8 | 1.5 | 1911-12..... | 2.8 | 6.0 | 4.5 |
| 1897-98..... | 3.8 | 6.4 | 5.4 | 1912-13..... | 3.4 | 6.9 | 1.5 |
| 1898-99..... | 2.6 | 6.2 | 4.7 | 1913-14..... | 0.5 | 5.1 | 6.6 |
| 1899-1900..... | 2.3 | 3.6 | 5.2 | 1914-15..... | 8.6 | 7.4 | 6.6 |
| 1900-1901..... | 2.0 | 0.2 | 0.6 | 1915-16..... | 3.5 | 6.0 | 8.1 |
| 1901-2..... | 1.2 | 1.3 | 3.2 | 1916-17..... | 6.3 | 1.8 | 2.7 |
| 1902-3..... | 1.9 | 3.0 | 1.1 | 1917-18..... | 5.7 | 3.9 | 1.0 |
| 1903-4..... | 2.0 | 2.5 | 4.4 | 1918-19..... | 1.4 | 0.5 | 1.6 |
| 1904-5..... | 4.8 | 4.1 | 0.5 | 1919-20..... | 8.5 | 8.6 | 2.6 |
| 1905-6..... | 3.8 | 2.9 | 2.0 | | | | |

Negative departures in ordinary type, positive in full-faced type.

¹ This is a discussion of the specific problem of long range forecasting for the Pacific coast. It is not identical with the paper by the same author mentioned in the preceding article.—A. J. H.

Remarks on Table 1.—The figures of the above table show the seasonal distribution of the precipitation for each of the 29 years, the magnitude as well as the sense of the departures. It will be noted that the distribution about the mean is not symmetrical, there being more seasons with negative than positive departures, but since this is a general characteristic of rainfall distribution elsewhere no particular significance is attached to it. The standard deviation has been computed for each district; the figures are as follows:

| | Inches. |
|---------------------|------------|
| North Pacific..... | ± 2.97 |
| Middle Pacific..... | ± 1.67 |
| South Pacific..... | ± 1.24 |

In but 2 of the 29 years, or 7 per cent of the time, was the departure uniformly positive in all three districts and in but 9 of the years was it uniformly negative. In the remaining 19 years a mixed distribution obtains.

There seems to be a fairly sharp dividing line between the north and middle Pacific regions, respectively, in the matter of seasonable distribution, with a tendency for years of like character to repeat, occasionally. See the group of years 1896–1899 with positive departures in the north Pacific and negative in both the middle and south Pacific. See also the two groups of years 1907–1909 and 1914–15, in both of which the first and second years show an excess in the southern regions, followed by an excess in the third year in all three districts. This sequence might indicate that the meteorological conditions favorable to precipitation developed progressively, reaching a climax in the third year, and again it may be a purely fortuitous occurrence.

It will be noticed that the distribution of the departures about the mean is not symmetrical, there being but 33 positive departures and 54 negative, or 38 and 62 per cent respectively. This, however, is a world-wide characteristic of the distribution of precipitation. I have found a similar characteristic to attach to departures of mean pressure from the normal, there being more positive than negative departures in all of the cases thus far examined. Since high pressure is inimical to the occurrence of precipitation there may be a closer bond of union between the two phenomena than has hitherto been suspected.

There appears to be sufficient physical grounds for the distribution of precipitation as shown in the above table; I shall now consider some of them in detail.

WET AND DRY SEASONS ON THE PACIFIC COAST.

I distinguish three classes of wet winters on the Pacific coast, viz, (1) those which give heavy rains in all of the States, particularly in California, (2) those in which the rainfall is deficient in Washington and Oregon and in excess in California, and, finally, (3) those in which the reverse is true.

In each case the general control is doubtless the pressure distribution in that part of the globe embraced by the eastern Pacific and the western half of the North American continent. This part of the earth's surface contains two of the so-called great centers of atmospheric action, viz, the Aleutian Low and the Pacific HIGH. The first named is a pronounced feature of the winter circulation only and is known to vary both in its intensity and the geographic position it occupies from season to season, although the law of variation is not known. The exact position of the Pacific HIGH is known from ships' observations only; and while it too is known to shift its position slightly from month to month, its

variations in latitude and longitude are not so well known as those of the Aleutian Low.

The precipitation of Pacific Coast States is great or small according as to whether areas of low pressure enter the continent and move eastward in low or high latitude. In years of deficient precipitation in California the LOWS of the month or season will be found to have entered the continent and moved eastward north of the mouth of the Columbia River.

In years of abundant precipitation the movement of areas of low pressure is east or southeast, passing inland south of the mouth of the Columbia. This is, however, a very broadly generalized statement and must be interpreted accordingly.

I shall now consider more in detail the conditions which are associated with the several types of wet winters on the Pacific coast beginning with no. 1—a wet winter in all of the States.

This type is represented by the winters of 1909 and 1916, each of which included at least one month of exceptionally heavy precipitation—so heavy in fact as to give character to the whole winter. The particular point to which I desire to call attention is that the heavy rain is rarely continuous throughout the entire season but is more likely to be concentrated in a period of a month or slightly longer, the remainder of the season being relatively dry. January, 1909, had the largest number of rainy days at San Francisco, Calif., during a period of 60-odd years. The explanation is found in the daily weather maps of the month. From these it can be seen that the Aleutian Low evidently extended to the coast of the North American continent south of latitude 45° on many days of the month. In 1895, I had occasion to remark:¹

* * * The storms of the Pacific coast present a characteristic that is worthy of special study, viz, an apparent oscillation from the ocean to the land and vice versa, that is to say, the low approaches the coast and partially disappears, reappearing within 12 to 36 hours, and continuing this action until the storm finally disappears.

In the light of evidence that has come to hand within the last 25 years it is evident that the LOWS which approach the coast in the neighborhood of north latitude 45° are not always separate and distinct entities but rather merely manifestations of the great Aleutian LOW whose center is probably somewhere over the Gulf of Alaska, several hundred miles from shore. At times offshoots from this LOW pass inland over the continent, some of which eventually reach the Atlantic. In January, 1909, while but three individual LOWS passed inland the presence of the southeastern front of the Aleutian LOW off the coast was the cause of the nearly continuous rains in California. Another effect of the presence of this LOW was to modify profoundly the pressure distribution of the United States as a whole. The Great Basin HIGH,² characteristic of dry weather in California, was wholly absent, as it also was in January, 1919.

Considering now winters of the second class, viz, those with deficient precipitation in Washington and Oregon and normal or above normal in California, it is found that high pressure in Alaska, which causes easterly winds in the region north of the Columbia River, is prejudicial to rains in both Washington and Oregon; California, on the other hand, being in the region of light and variable winds, is generally well watered since, paradoxical as it

¹ MO. WEATHER REV., Jan., 1895, 23: 3.

² The term "Great Basin" as used in this paper refers to the northern portion of the western Cordilleran region which is characterized by wholly interior drainage. Roughly speaking, as here used, it comprises southeastern Oregon, southern Idaho, southwestern Wyoming, northern Utah, and northern Nevada. Representative Weather Bureau stations within this area are Salt Lake City, Utah, Winnemucca, Nev., and Boise, Idaho.

may seem, high pressure in Alaska, which is prejudicial to rain in Washington and Oregon, is favorable to rain in California, since one effect of the high pressure is to cause areas of low pressure to enter the State at a relatively low latitude and thus to cause moderate rains.

The third class—wet in Washington and Oregon and dry in California, of which the winters of 1896, 1897, 1898, and 1899 are examples, is evidently due to the building up of high pressure over the Great Basin. When this happens, areas of low pressure pass directly eastward over northern Washington or southern British Columbia, too far north to give rains except to the extreme north coast region of California. The building up of high pressure in the region west of the Rocky Mountains is clearly a result of the general circulation of the atmosphere, although the process may be facilitated by local conditions of snow cover and intensive radiation peculiar to parts of that region.

Dry winters.—It is easy to pass from the foregoing to a consideration of the pressure distribution which attends dry winters. As in the case of wet winters dry winters may be grouped according as the deficiency is general in all three districts or in but a single district. In what follows reference is made to those winters in which the deficiency in precipitation was general in all three districts. These years were 1891-92, 1892-93, 1899-1900, 1902-3, 1903-4, 1905-6, 1911-12, 1912-13, and 1919-20, in all nine winters in which there was a general deficiency in precipitation. The lack of precipitation seems to be clearly due to an intensification of the winter area of high pressure over the Great Basin; in some years this high extends to the westward as far as the coast with the result that areas of low pressure uniformly pass to the eastward north of the Columbia River, and dry weather in California as well as in Washington and Oregon results.

Since the Great Basin HIGH rarely persists so long as a month there must be intermediate periods when rain falls on the coast of Washington and Oregon. In California, however, rain is much less likely because the interval between the breaking down of one Great Basin HIGH and the building up of a second one is too short to permit of the development of areas of low pressure off the California coast. I have shown elsewhere that in the cold months the Great Basin HIGH is periodically renewed through the general circulation and that its semipermanent characteristics are more apparent than real.

The difficulty is establishing definite relations between pressure distribution and precipitation for Pacific Coast States is accentuated by the fact that the available statistics have been compiled for the month as a time unit. Monthly statistics at times but imperfectly reveal the actual conditions which were experienced. It must be kept in mind that only in cases of very pronounced disturbances of the normal conditions which, in the nature of the case are of infrequent occurrence, can the true relations be clearly perceived. An examination of the data as to wet and dry winters as presented in Table 1 shows at once the lack of uniformity in the distribution of precipitation on the Pacific coast and this is not unexpected when one considers that in the temperate zones the dominant weather controls are constantly changing from one extreme to the other. Periods of stable or fair weather and unstable or rainy weather follow one another apparently without rhythm or order;

so it happens that months which on the whole are dry may have short periods of abundant rains; space does not permit us to elaborate upon this idea, but a single example may be helpful.

The winter of 1902-3 appears in Table 1 as a season of deficient rainfall in the north and middle Pacific coast regions and of slightly more than the normal rainfall in the south Pacific region. The month of December, 1902, was wet in the north Pacific coast region and dry in California. It was followed by dry weather from January 1 to 19 generally throughout the entire region and from the 19th until the end of the month by a series of rainstorms which had they occurred earlier in the month and continued over a longer time would have changed the aspect of the month considerably; as it was, the total rainfall was slightly above the normal throughout California. This rainy period continued until about February 6 when a series of areas of high pressure moved into the Great Basin region completely dominating the weather in California for the remainder of the month. As we have before observed, high pressure in the Great Basin region is inimical to rain in California. The mean sea-level pressure at Boise, Idaho, for February 1903, was 30.30 inches. Now if we were to consider only the monthly mean pressures for January and February we would be justified in classing both months as dry, but we have seen that in each of them there was a short period of abundant rains.

It is now reasonably certain that the solution of the problem of seasonal rainfall forecasts for California, and in a sense for the States of Washington and Oregon also, lies in the anticipation of those great changes in the physical condition of the atmosphere over a large portion of the earth's surface, which changes in themselves induce other changes in the general circulation of the atmosphere, resulting later in important variations in the rainfall of the western portion of the North American continent.

If it can be foreseen, for example, that the atmosphere of the region occupied by the Aleutian Low will be of greater density than usual, that the geographic boundaries of this Low will be greatly restricted in space, then, it is believed the discharge of polar air to lower latitudes will be facilitated and the rainfall of Washington and Oregon will be deficient; if, on the other hand, the reverse conditions obtain we shall probably be justified in predicting abundant rainfall in the Pacific Coast States.

Following out the thought elsewhere expressed, that the key to weather changes is to be sought in variations in atmospheric pressure, I have computed the 12-month consecutive means of pressure for Honolulu, Hawaii, San Diego, Calif., and Salt Lake City, Utah, for 29 years, 1892 to 1920, both inclusive; also for Sitka, Alaska, Jan., 1909-Dec., 1919. Twelve-month consecutive means are obtained as follows: Compute, for example, the arithmetical mean of the 12 calendar months, which in ordinary practice would represent the annual mean. Instead of calling it the annual mean, let us consider it as the mean for the middle point of the period, viz, July 1; then form a new sum by dropping the first term of the original sum and adding that of the 13th month from the origin, dividing by 12, and so on indefinitely. Expressed in mathematical language, $(M_1 + M_2 + M_3 + \dots + M_{12} \div 12)$; $(M_2 + M_3 + M_4 + \dots + M_{13} \div 12)$ would represent the consecutive or overlapping means in any series where M_1 , M_2 , and M_3 are consecutive monthly means in the series. Means thus obtained were used in this country by Clayton and later by Arctowski. The advantage they possess is that both the short and the long period varia-

* Weather Forecasting in the United States, Weather Bureau, Washington, 1916, p. 132.

tions in the data are readily perceived. Care should be exercised in making comparisons between two places widely separated in order not to confuse that which may be due to the accident of geographic position with results which may be due to changes in the general circulation of the atmosphere.

An examination of these data shows at once that the accidental pressure changes at Honolulu are less frequent and that the amplitude of the oscillations up and down is very much smaller than at the more northerly stations of the North American continent. Plotting the data gives four very instructive curves. It is seen at once that the larger progressive changes at these widely separated places are sometimes in the same sense, at other times in an opposite sense, and at still other times there seems to be little, if any, relation between the curves. A parallel movement in the curves is seen in the maxima of 1893-94 and 1917. In the first named the peak of the maximum was reached at Honolulu in February, at San Diego two months later, and at Salt Lake four months later. From the general course of the curve and the lag in the maximum at the last named, as compared with San Diego, it is suspected that after

on the Pacific coast can not be based on Alaskan pressures, unless, indeed, the pressure distribution itself can be forecast.

It has been suggested in some quarters that there is a tendency on the part of the weather to persist, once a type has become well established. This tendency is recognized and made use of by forecasters, but it can never assume importance in seasonal forecasting, simply because thus far no forecaster has been able to anticipate in advance when the type in question would set in, and after it has set in as to just when it would revert to an entirely different type.

I have thought it worth while, however, to compare the December mean station pressures at Salt Lake City, Utah, with the pressures in the immediately following months of January and February. Salt Lake was selected partly on account of its geographic position, being nearly in the center of the Great Basin region, and partly because the record for the period 1892-1920 is complete.

It appears from an examination of the monthly departures that the December departure was followed in the succeeding month of January by departures of the same sign, regardless of the magnitude, in 14 out of

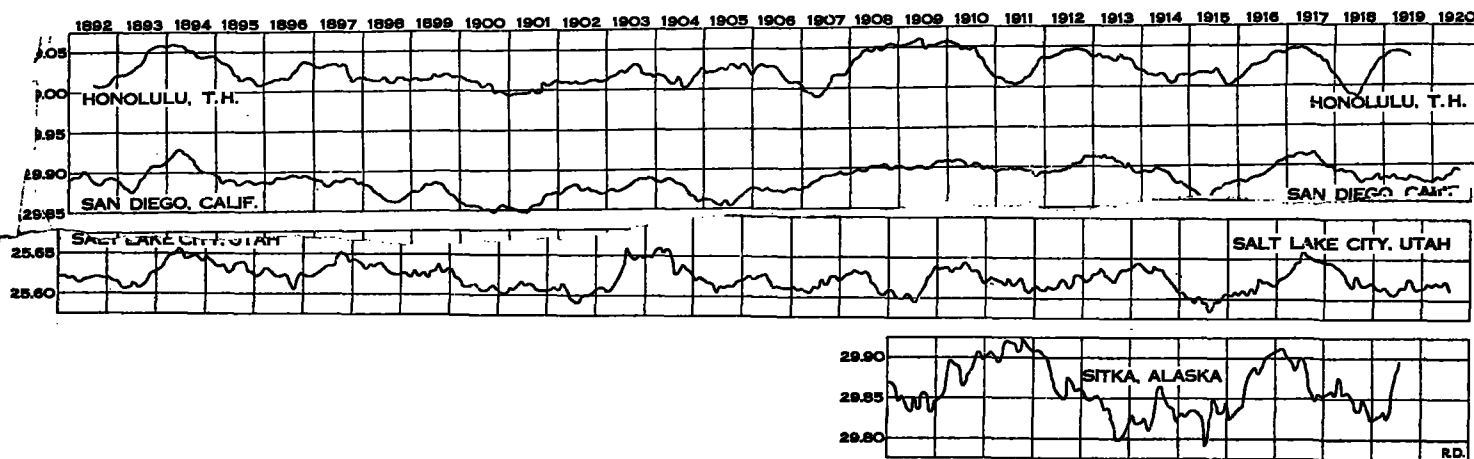


FIG. 1.—12-month consecutive means of pressure.

all there is not a simple progressive motion from west to east, but that the pressure at Salt Lake is conditioned by factors which do not apply to San Diego or Honolulu. The extensive maximum of 1917 first appeared at Sitka in February, at Honolulu in April, at Salt Lake in June, and at San Diego in July. This sequence would seem to indicate a movement fan-shaped to the south and west. The course of the present curve for Sitka seems to negative the idea that pressure at that station varies in the opposite sense to that at Honolulu, although there are times when that is true in part.

The sudden and intense fluctuations in the pressure at Sitka from one month to the next and the general character of the progressive changes must surely militate against the use of the Sitka pressures in seasonal forecasting. It is conceivable that a slight variation in the geographic position of the Aleutian LOW would bring the station Sitka within its influence and, on the other hand, a slight surge of the interior continental HIGH to the westward would bring the station within a region of high pressure. And, moreover, since the interval between the appearance of any certain type of pressure distribution in Alaska and its effect upon the weather in the western part of the United States is, at most, only a day or so, it can be readily seen that seasonal forecasts of weather

the 29 winters examined; in other words there is about an even chance that the pressure departure of January will be of the same sign as that of December. January and February being compared in like manner give precisely the same result, therefore it seems reasonable and probable that whenever the pressure at Salt Lake City or other station in the Great Basin region is below the normal in December there is about an even chance that it will be below in the ensuing month of January, and this condition, i. e., low pressure in the Great Basin region in winter is favorable to abundant precipitation in California in the corresponding months. The converse, high pressure in the Great Basin region is inimical to precipitation in California. It is interesting to note that the winters of heavy precipitation in California, 1895-96, 1906-7, 1908-9, 1913-14, 1914-15, and 1915-16 were, with but one exception, winters of diminished pressure in December at Salt Lake City. It must not be understood that these two events, low pressure in the Great Basin and increased precipitation in California, stand in the relation of cause and effect, but rather that the low pressure in the Great Basin is part and parcel of a much more extensive change in the pressure distribution that is directly concerned with the occurrence of precipitation in Pacific Coast States.

For comparison with the data of Table 1, rainfall departures, I give in the subjoined table the station pressure departures for the winter months at Salt Lake City.

TABLE 2.—Departure from the normal of station pressures at Salt Lake City, Utah, winter months only.

[In thousandths of an inch.]

| Years. | De- cember. | Janu- ary. | Feb- ruary. | Years. | De- cember. | Janu- ary. | Feb- ruary. |
|----------------|----------------|---------------|----------------|--------------|----------------|---------------|----------------|
| 1891-92..... | 0.077 | 0.042 | 0.023 | 1906-7..... | 0.024 | 0.102 | 0.061 |
| 1892-93..... | .025 | .048 | .002 | 1907-8..... | .048 | .036 | .011 |
| 1893-94..... | .041 | .025 | .034 | 1908-9..... | .010 | .127 | .073 |
| 1894-95..... | .024 | .122 | .075 | 1909-10..... | .059 | .012 | .021 |
| 1895-96..... | .028 | .014 | .081 | 1910-11..... | .031 | .038 | .045 |
| 1896-97..... | .048 | .014 | .073 | 1911-12..... | .064 | .003 | .032 |
| 1897-98..... | .062 | .004 | .084 | 1912-13..... | .038 | .017 | .069 |
| 1898-99..... | .112 | .001 | .024 | 1913-14..... | .007 | .065 | .057 |
| 1899-1900..... | .063 | .072 | .000 | 1914-15..... | .069 | .057 | .071 |
| 1900-1..... | .073 | .002 | .020 | 1915-16..... | .064 | .204 | .085 |
| 1901-2..... | .033 | .024 | .048 | 1916-17..... | .136 | .010 | .031 |
| 1902-3..... | .029 | .002 | .037 | 1917-18..... | .018 | .064 | .005 |
| 1903-4..... | .114 | .296 | .078 | 1918-19..... | .030 | .104 | .125 |
| 1904-5..... | .005 | .044 | .063 | 1919-20..... | .052 | .084 | .037 |
| 1905-6..... | .063 | .036 | .023 | 1920-21..... | .092 | | |

Negative departures in ordinary type; positive in full-faced type.

CONCLUSIONS.

The effort has been made in the foregoing analysis to discover from the available observational material, which is confessedly inadequate, the true nature of the weather phenomena associated with years of heavy and years of light precipitation on the Pacific coast. This effort has been aided and supplemented by the personal experience of the writer in weather forecasting from synoptic charts and his contact for many years with the daily weather maps of the United States and Canada. The most valuable asset that one can bring to the study of the problem is that of experience in forecasting the day-to-day weather. There are several fundamental facts which can not be so readily grasped in any other way. These are: (1) The general instability of cyclonic and anticyclonic systems; that is to say there is little, or no assurance, that, for example, when a cyclonic system enters the continent from the Pacific it will endure for any specified time; that its motion will continue in the original direction or be in a different course and finally whether its original speed will remain constant, increase or diminish. (2) That, so far as the forecaster can perceive this general instability is conditioned upon the pressure, temperature, and moisture-content of the atmosphere at the moment, not only in the immediate field of observation but also in distant regions. (3) That, while the distribution of heat undoubtedly sets in motion a series of movements in the atmosphere which result in the origin of cyclones and anticyclones, yet the controlling factor or factors which set in motion, maintain, and change the nature of these phenomena have not yet been recognized with sufficient definiteness to be useful to the day-to-day forecaster. The conclusion is therefore irresistible that the explanation of variations in the weather of the United States and other regions in the same latitude is to be found in a study of the general problem of atmospheric circulation, particularly as to those influences which control or modify the slow interchange of air between the equator and the poles. This interchange I believe is largely brought about by the development and movement of cyclones and anticyclones which as is well known differs from season to season. The problem therefore is first to attempt to predict the temperature,

the moisture content and the movement of the atmosphere over that portion of the globe embraced between the 90th and 180th meridians of west longitude and 20° to 60° of north latitude. Local conditions as to temperature, whether of land or water, in parts of this area are seemingly inadequate to account for the great changes in the air currents which are associated with variations in precipitation.

The futility of attempts to show a relation between the changing spottedness of the sun and terrestrial weather becomes more and more apparent as one seriously examines the terrestrial data in connection with weather extremes of whatsoever character. While it is not yet possible to forecast in advance the rainfall for a season by a rational deductive process, I may at least point out the line of action which might lead to the accomplishment of that object.

The greatest need at the present time is for observation from the Pacific which will enable one to delimit the area of high pressure the center of which normally in October, let us say, is found about latitude 30° north and longitude 140° west. At the same time, our knowledge of the intensity and geographic extent of the Aleutian low should be extended and this can be done best through ships navigating the waters of the Pacific to the southwest of the westernmost part of the Aleutian chain. By charting these observations day by day for at least 25 years, sufficient knowledge will be available to at least discuss the problem intelligently.

It is assumed of course that 25 years' additional observations from Honolulu, Midway Island, and Alaska will also be available.

NOTE ADDED MARCH 26, 1921.

In a discussion with officials of the Weather Bureau staff after the completion of this paper, it was brought to my attention that in 1898 it was suggested on the evidence afforded by three years' temperature observations at Dutch Harbor, Alaska, that high temperature in the Aleutian group is followed three months later by increased precipitation in California. The proponent of the proposition was well aware of the fact that the short temperature record then available afforded but slight grounds for the belief that the relation was real. Subsequent discussion, particularly that of Mr. Alexander McC. Ashley of the Central Office of the Weather Bureau, in January, 1901,¹ showed that the favorable evidence of the short temperature record was probably merely a coincidence, and should not be considered as indicating the existence of a real connection.

However, since any observational material within the region of the semipermanent Aleutian low must be helpful to a better understanding of the phenomena of the weather in that region, I have thought it advisable to consider the original proposition de novo, in the light of more abundant temperature observations which are now available. I have therefore consolidated the two chief series of temperature observations, the one at Dutch Harbor, Alaska, which was begun by the United States Signal Service in 1882, and resumed by the Weather Bureau in 1905; the other a cooperative record made on Unga Island, Alaska, about 240 miles east of Dutch Harbor, begun in 1886 and ended in 1910, although the last year has been rejected. There were, however, aside from

¹ Long Range Seasonal Forecasts for the Pacific Coast States, Alexander McC. Ashley MON. WEATHER REV., 29: 16.

that year, nearly four years' observations made concurrently with those at Dutch Harbor, from which it has been possible to deduce a series of monthly corrections to reduce the Unga Island record to that of Dutch Harbor. Consolidating the two records after applying a constant correction to the monthly means of Unga Island, I get the nearly continuous record presented in Table 3, next following:

TABLE 3.—Monthly mean temperature at Dutch Harbor, Unalaska Island, Alaska. [F.]

[Latitude, 53° 54' N.; longitude, 166° 32' W.; elevation, 30 feet.]

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1882..... | 36.5 | 31.4 | 34.4 | 37.2 | 42.6 | 46.6 | 51.3 | 52.2 | 47.9 | 43.8 | 37.0 | 27.8 |
| 1883..... | 34.5 | 31.2 | 30.6 | 32.6 | 40.1 | 45.9 | 49.9 | 50.4 | 46.0 | 43.4 | 36.3 | 30.6 |
| 1884..... | 33.6 | 36.5 | 38.7 | 36.5 | 39.2 | 45.7 | 50.8 | 50.3 | 48.1 | 40.6 | 36.8 | 35.0 |
| 1885..... | 37.2 | 27.4 | 31.7 | 36.6 | 41.7 | 45.2 | 48.8 | 50.3 | 45.1 | 41.5 | 35.5 | 33.9 |
| 1886..... | 33.6 | 27.9 | 32.2 | 36.1 | 42.3 | ..... | 54.6 | 54.0 | 48.9 | 39.8 | 30.2 | 26.3 |
| 1887..... | 28.8 | 32.5 | 29.4 | 36.6 | 37.7 | 48.4 | 49.6 | 51.0 | 47.9 | 39.8 | 31.2 | 28.3 |
| 1888..... | 38.8 | 34.5 | 40.4 | 34.6 | 43.7 | 49.4 | 49.6 | 58.0 | 47.9 | 41.8 | 29.2 | 31.5 |
| 1889..... | 38.8 | 27.0 | 35.4 | 35.6 | 36.7 | 47.2 | 48.8 | 50.4 | 38.9 | 37.8 | 32.2 | 32.3 |
| 1890..... | 31.6 | 28.6 | 31.7 | 33.0 | 38.9 | 43.5 | 49.4 | 53.1 | 46.9 | ..... | ..... | ..... |
| 1891..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 55.5 | 49.8 | 41.6 | 36.3 | 21.4 |
| 1892..... | 29.0 | 25.7 | 25.4 | 37.4 | 43.0 | 51.3 | 52.8 | 53.9 | 46.3 | 38.5 | 35.1 | 33.7 |
| 1893..... | 29.7 | 33.6 | 34.7 | 37.5 | 39.6 | 48.1 | 49.3 | 49.6 | 48.7 | 39.2 | 34.8 | 32.7 |
| 1894..... | 27.7 | 22.9 | 29.9 | 32.6 | 33.6 | 43.9 | 51.1 | 50.8 | 47.2 | 37.6 | 32.7 | 27.7 |
| 1895..... | 27.1 | 30.6 | 30.7 | 30.4 | 38.4 | 45.8 | 48.4 | 50.4 | 46.5 | 40.3 | 36.6 | 26.4 |
| 1896..... | 23.1 | 20.5 | 34.0 | 34.2 | 37.1 | 45.6 | 48.8 | 50.3 | 46.7 | 40.2 | 37.1 | 29.6 |
| 1897..... | 34.0 | 35.4 | 29.7 | 39.0 | 42.3 | 46.0 | 49.8 | 53.1 | 48.1 | 38.8 | 38.3 | 35.7 |
| 1898..... | 34.0 | 25.3 | 38.6 | 39.1 | 39.4 | 44.7 | 50.8 | 49.6 | 46.7 | 39.8 | 35.2 | 30.5 |
| 1899..... | 29.2 | 33.5 | 37.1 | 38.4 | 38.2 | 48.0 | 52.6 | 51.6 | 47.7 | 42.4 | 35.6 | 28.3 |
| 1900..... | 30.9 | 36.5 | 35.8 | 34.8 | 39.3 | 48.9 | 49.1 | 53.2 | 48.3 | 42.2 | 35.8 | ..... |
| 1901..... | 34.0 | 30.8 | 30.0 | 34.5 | 37.5 | 44.7 | 49.5 | 51.2 | 46.8 | 39.6 | 32.2 | 32.4 |
| 1902..... | 34.0 | 35.5 | 34.2 | 35.6 | 41.1 | 52.0 | 53.5 | 51.5 | 47.6 | ..... | ..... | ..... |
| 1903..... | 26.0 | 31.1 | 37.4 | 36.1 | 39.3 | 46.2 | 47.8 | 50.6 | 47.0 | 36.3 | 29.8 | 32.2 |
| 1904..... | 29.0 | 28.3 | 32.4 | 33.8 | 38.7 | 44.3 | 47.9 | 48.8 | 48.3 | 39.4 | 30.8 | 25.7 |
| 1905..... | 34.2 | 34.7 | 35.2 | 41.2 | 41.5 | 47.0 | 52.3 | 52.7 | 46.1 | 41.5 | 37.4 | 30.5 |
| 1906..... | 26.6 | 33.4 | 31.9 | 35.2 | 39.0 | 44.0 | 48.4 | 49.8 | 48.7 | 41.4 | 35.2 | 35.1 |
| 1907..... | 37.6 | 26.4 | 37.2 | 33.1 | 39.4 | 47.1 | ..... | ..... | ..... | 40.0 | 34.2 | 30.0 |
| 1908..... | 28.2 | 32.4 | 30.3 | 30.0 | 38.1 | 45.6 | 48.4 | 50.3 | 46.9 | 41.5 | 33.8 | 34.8 |
| 1909..... | 31.8 | 34.1 | 30.0 | 37.0 | 39.6 | 46.0 | 52.1 | 52.7 | 44.0 | 40.4 | 36.6 | 30.6 |
| 1910..... | 31.8 | 33.2 | 28.0 | 30.4 | 42.2 | 47.8 | 57.6 | ..... | 49.5 | 41.4 | 33.8 | ..... |
| 1911..... | 33.8 | 34.8 | 34.6 | 36.6 | 40.8 | ..... | 54.2 | 55.4 | 48.8 | ..... | 38.0 | 31.9 |
| 1912..... | 31.7 | 33.0 | 35.2 | 37.8 | 39.8 | 44.9 | 49.8 | 50.2 | 46.6 | ..... | 34.8 | 29.0 |
| 1913..... | 32.6 | 35.7 | 37.0 | 35.7 | 39.9 | 47.0 | 50.0 | 50.8 | 46.5 | 40.8 | 36.2 | 29.6 |
| 1914..... | 30.4 | 36.4 | 34.4 | 38.0 | 42.8 | 46.2 | 53.9 | 53.0 | 51.3 | 41.8 | 37.0 | 36.5 |
| 1915..... | 29.6 | 30.5 | 34.0 | 35.7 | 43.3 | 49.2 | 52.6 | 50.8 | 49.4 | 42.4 | 36.8 | 32.6 |
| 1916..... | 35.4 | 29.4 | 27.5 | 33.2 | 37.4 | 42.2 | 48.0 | 49.3 | 46.8 | 42.8 | 34.4 | 30.8 |
| 1917..... | 28.8 | 34.2 | 33.5 | 33.4 | 40.8 | 46.4 | 53.6 | 50.8 | 47.9 | 42.2 | 29.4 | 32.8 |
| 1918..... | 30.8 | 31.8 | 34.6 | 36.4 | 43.0 | 45.4 | 51.4 | 51.0 | 45.4 | 40.5 | 32.6 | 31.5 |
| 1919..... | 23.3 | 29.0 | 35.1 | 32.3 | 38.6 | 45.8 | 50.8 | 49.8 | 49.2 | 42.6 | 35.8 | 34.4 |
| Means. | 31.6 | 31.2 | 33.7 | 35.6 | 39.9 | 46.5 | 50.8 | 51.6 | 47.3 | 40.7 | 34.2 | 30.4 |

This series affords dependable monthly means for about 37 years, and, in a limited sense, may be considered as reflecting the water temperatures of the north Pacific, in the region of the Aleutians, for those years. I have computed the departures for the months August to December, both inclusive, for comparison with the monthly precipitation departures of the middle Pacific coast region—mainly northern and central California—for the months November to March, inclusive.

Comparisons have been made by means of graphs, and I have also made a dot chart (fig. 2), plotting August departures of Aleutian temperatures against departures in California precipitation in November; also September Aleutian temperatures against December precipitation in California. It is evident from the scatter of the dots that there is no orderly relation between the two events. Graphs yield the same result; and moreover, Mr. R. H. Weightman, of the Central Office, in an unpublished manuscript, has reached identical conclusions.

In this connection, I have reread Prof. McAdie's article in the April, 1908, MONTHLY WEATHER REVIEW (p. 99), in which he deduces two general laws for forecasting on the Pacific coast, viz:

A. When the continental high overlies Oregon, Idaho, Utah, and Nevada, the general drift of the surface air is from the north or northeast, and such a circulation favors fair weather with little precipitation. * * * Individual lows are restricted to northern counties and pass eastward without extending southward.

B. When the north Pacific low area (the Aleutian low) extends well southward along the Oregon coast and the continental high overlies Assiniboia [now Saskatchewan] and Montana, the general drift of the surface air in California is from the south or southeast. Conditions (then) favor unsettled weather, with frequent heavy rains west of the Sierra and heavy snowfall in the Sierra. Individual highs appear with little warning north and east of the Kootenai, and move, as a rule, slowly south. Individual lows appearing over Vancouver Island and the north coast of Washington deepen and also extend southward, the rain-area reaching northern California in 12 hours, the central coast in 24 hours, and the coast south of Point Conception in 36 hours.

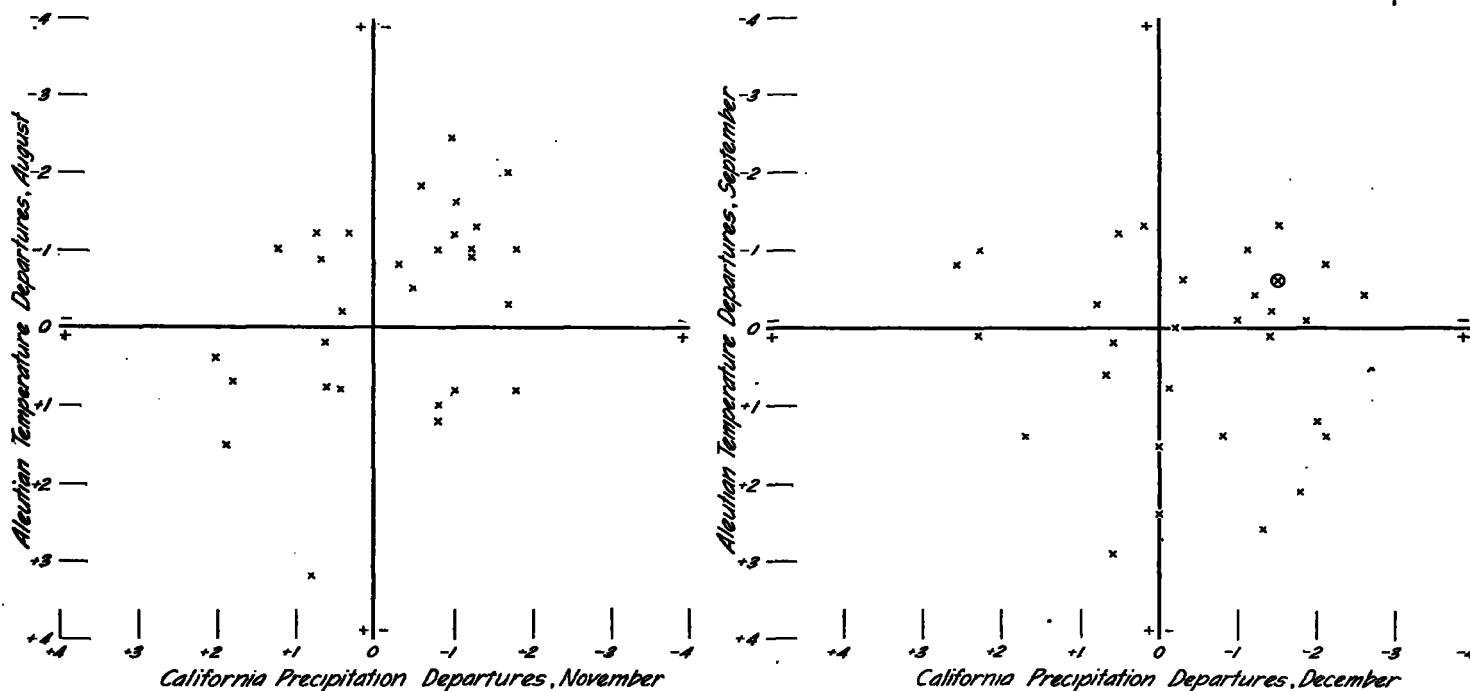


FIG. 2.—On left, Aleutian temperature departures of August and precipitation departures in California, three months later; on right, the same, but for September temperatures and December precipitation.

The above statement of the general principles which obtain in forecasting for the Pacific coast, are in close accord with the conception of the problem as presented in this paper.

RECORD-BREAKING RAINFALL IN JAMAICA IN JANUARY, FEBRUARY, AND MARCH, 1921.

(Excerpts from *Jamaica Weather Report*, Feb. and Mar., 1921, p. 4.)

The mean rainfall for the entire Island during February was somewhat over twice the normal. Moore Town,

in Portland Parish, had a total fall of 27.73 inches during the month, while at Belvedere, in the same parish, there was a 24-hour fall of 9.05 inches. The average precipitation for the Island was 7.22 inches—the greatest amount for any February in 50 years. It is worth noting that the average rainfall for January of this year was 10.87 inches, being the greatest of any January on record. The rainfall for March was 84 per cent above normal.—*H. L.*

APPLIED CLIMATOLOGY IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau Office, San Francisco, Calif., May 17, 1921.]

551.58 (794)

SYNOPSIS.

The work done at a climatological section center of the Weather Bureau furnishes good evidence of the many and varied applications of climatology. These are not known to the general public, and even professional meteorologists have but a limited appreciation of their extent and variety. The practical applications of climatology in California are here briefly enumerated and described in the hope that the survey may be of interest and perhaps of value in other climatological sections, and with a desire that it may inspire similar surveys of other regions. In California the Weather Bureau acts as a meteorological and climatological center of information and clearing house, and supervises the gathering and publication of a small fraction of the data available. Municipalities, industries, public service corporations, business houses, resorts and institutions maintain climatological stations and secure data which are of great practical value in agriculture, manufacture, industry, mining, transportation, aviation, conservation, public service, advertising, public health and recreation.

INTRODUCTION.

Because of its vast size, its wide range of latitude, its uneven topography and the contrasts of climate which result therefrom, California presents great variety in the uses and applications of climatology, a variety which is probably not equaled by any other State. The following is a brief survey of applied climatology in California, a field which is so extensive that only the salient features can be here referred to.

WEATHER BUREAU ACTIVITIES.

Practically all of the meteorological and climatological activities of the United States Government in California are conducted by the Weather Bureau. While this is the largest single organization engaged in the task of accumulating meteorological and climatological data and making the same available for public use, its activities represent only a small fraction of the total work of this kind carried on in this State. The Weather Bureau serves as a meteorological and climatological clearing house. But the demands for detailed data are so extensive, and these demands are increasing so rapidly that the limited appropriations allowed the Weather Bureau do not permit it to render as complete service as might be rendered with more liberal appropriations.

Briefly stated, the Weather Bureau maintains 11 regular first-class stations, situated at the following places: San Francisco, Los Angeles, Sacramento, Fresno, San Diego, Eureka, Red Bluff, San Jose, San Luis Obispo, Independence, and Point Reyes. The first named is the district forecast center and the climatological section center. Special attention is paid to river and flood data at Sacramento, Fresno, and Eureka. Marine vessel movements are reported at Point Reyes. Storm warning stations are located at eight prominent points along the coast. In addition, approximately 300 climatological substations are maintained, but the

observers at only about 10 per cent of these receive nominal compensation (because of special observations and service required), the others being volunteer and unpaid cooperative observers. At all stations special attention is paid to precipitation data, since precipitation is the most important element of climate in California. The Weather Bureau has the cordial cooperation of all the various agencies engaged in gathering weather data, but the extent of the cooperation varies, since the Bureau is unable to supervise the gathering and the publication of more than a small fraction of the data available.

MUNICIPAL CLIMATOLOGY.

The municipal governments of two cities, Oakland and Santa Barbara, have installed the complete meteorological equipment of a first-class Weather Bureau station, including the triple register. In Oakland the apparatus forms part of the equipment of Chabot Observatory, a suburban observatory which is maintained under the auspices of the board of education and is open to public inspection during certain hours. It is a combined meteorological and astronomical observatory, ideally and permanently located on a large tract of land at the edge of the city. At Santa Barbara the municipality has installed complete meteorological apparatus on the grounds surrounding the home of one of its prominent residents. More than \$1,000 has been expended in standard equipment with the hope that the Weather Bureau may eventually take over the same and maintain a first-class station at this place.

The city of San Francisco is at present building an aqueduct which will eventually bring water to the city from the Hetch Hetchy Valley, almost 200 miles distant. Since climate and particularly precipitation is an important factor in construction, water supply and hydroelectric power, the municipality maintains two weather stations in the drainage basin, namely, at Hetch Hetchy and Lake Eleanor.

Likewise, the city of Los Angeles, whose aqueduct is complete and in operation, maintains several climatological stations along its route, notably at Fairmont and in the Owens Valley.

The city of San Diego also maintains such a station at Barrett Dam, a link in its water supply system.

The city of Vallejo, the municipality adjoining the United States Navy Yard at Mare Island, has recently installed 36 standard 8-inch rain gages in an elevated valley which it proposes to use as a drainage basin for its future water supply, if the precipitation there comes up to expectations.

A number of communities maintain climatological stations under the supervision of a city official, usually